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Zinc pulverization alleviates the adverse effect of water deficit on plant growth, yield and nutrient acquisition in grapevines (*Vitis vinifera* L.)

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A R T I C L E I N F O

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A B S T R A C T

Grapevine (*Vitis vinifera* L.) is an important dryland pulse crop in many parts of the world. However, productivity and quality are often limited by periods of water deficit. In a number of drought regions, drought is accompanied with zinc (Zn) deficiency, one of the most serious problems causing significant decreases in yield and quality in viticulture. In spite of this fact, possible effect of Zn treatment to alleviate the adverse effect of water stress on grapevines has not been studied. A pot culture research was designed under controlled glasshouse condition with the objective to investigate the effects of Zn pulverization on growth, physiology and nutrient acquisition of grapevine cultivars 'Italia' and 'Alphonse Lavallée' subjected to different irrigation levels. Six years old grapevines of the cultivars grafted on a drought tolerant rootstock Richter 99 (*Berlandieri* x *Rupestris*) were cultivated in pots (70 L) and subjected to two different irrigation regimes, FI-100% (replenishing the substrate water storage up to field capacity) and DI (40% of FI). Half of the vines for each irrigation group received leaf Zn pulverization (1%) twice (prior to flowering and berry set). DI caused overall decreases in shoot and leaf developments of cultivars, while Zn pulverization had alleviating effects on such vegetative growth in general. Generally, leaf chlorophyll content of the vines was also improved by Zn under both FI and DI conditions. Spraying of the leaves and green bunches with chelated Zn supported the grapevines of both cultivars 'Italia' and 'Alphonse Lavallée' in varying degrees by improving acquisition of many plant nutrients, promoting the vegetative and generative developments. Considering the overall response of the vines to Zn pulverization with a particular concern to DI condition, improved shoot and leaf growth, greener leaves, enhanced berry development and vine yield allow us to recommend Zn spraying as an environmentally friendly and sustainable cultural practice under drought stress which has been increasing with global climate change.

1. Introduction

Most of the vineyards around the world experience seasonal or long-term drought in conjunction with high temperature and radiation. It is estimated that nearly 1.8 billion people will be faced with absolute water shortage in the first quarter of the twenty-first century and 65% of the human population will live under conditions of partial shortage of water (Nezhadahmadi et al., 2013). Global climate change, causing temperature extremes and more frequent water deficit in agricultural areas, is also adversely influencing the grapevine phenology, physiology and development throughout the world (Webb et al., 2007). Jones et al. (2005) have already reported that certain European grape-growing regions are approaching to exceed the thresholds of temperature and rainfall for optimum grapevine growth. More frequent extreme weather is predicted by most models, along with a significant increase of the summer air temperature and water stress, particularly for regions with a Mediterranean-type environment (Tubiello et al., 2000), where a great majority of world grape production is found. If the climate change course proceeds, grape yield and quality will be seriously affected in the near future. Thus, viticulturists have to perform better adaptive strategies to ensure production of economically high quality grapes at acceptable yields under dryer climate conditions in order to match the food demands of ever-increasing world population. The use of genetically drought tolerant rootstock and scion materials is the primary strategy among various options one of which is the use of environment friendly and cost effective plant protection way. Grapevine is one of a well-known drought avoidance species (Schultz, 2003), although its degree of water loss control under stressful conditions depends on physiological and functional properties that have rarely quantified in experimental studies. In Mediterranean type agro-ecosystems,

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grapevine genotypes belonging to *Vitis vinifera* L. species have traditionally been grown in marginal ecologies without irrigation in spite of the fact that rainfall generally does not meet the evapotranspirative demand of vines. The efficient management of limited water resources in Mediterranean agriculture requires irrigation scheduling techniques based on deficit supply. However, irrigation waters in grape growing areas are usually alkaline with a pH higher than 7.0 level. Watering plants with alkaline water over the vegetation period inevitably raises the pH of growth medium. Too high a pH, greater than 6.5, increases the incidence of micronutrient deficiencies. Furthermore, many of the soils in regions, where viticulture is main crop, have low available zinc (Zn) and frequently requires Zn fertilization. Consequently, grapevines may be challenged by water deficit and Zn deficiency simultaneously. By reducing root growth, Zn deficiency may limit the ability of the crop to use the moisture reserves in the soil (Nable and Webb, 1993). Sharma et al. (1994) indicated that Zn deficiency causes a reduction in the instantaneous transpiration efficiency of leaves. Zn is one of the essential micronutrients and an integral component or activator of a number of enzymes that represent almost all plant enzymatic groups. But, interestingly, the effect of Zn nutrition on the response to water stress has received little attention in experimental studies. In fact, Zn deficiency is a widespread micronutrient disorder in different agroclimatic regions of the world, particularly within arid and semi-arid areas (White and Zasoski, 1999) where viticulture is widespread. Under drought condition, Zn mobility in the soil is extremely low (Cakmak et al., 1996) and thus Zn acquisition is commonly reduced by low water availability. Grewal and Williams (2001) indicated that the ability of plants to cope with water stress during vegetation period could be enhanced with adequate Zn supply. Vitosh et al. (1994) demonstrated that several crops, including grapes have most sensitivity to Zn deficiency. In grapes, poor fruit set and "hen and chicken" bunches of variable sized berries may occur due to Zn deficiency even when leaf symptoms are not observed. It was documented that Zn foliar application is a simple way for making quick correction of plant nutritional status, as reported by Erenoglu et al. (2002). Accumulating evidence proven that mineral-nutrient status of plants plays a fundamental role in increasing plant ability to resist to adverse stress conditions (Khan et al., 2004). Zn nutritional status of plants may affect their drought sensitivity (Cakmak, 2000). Zn-deficient plants use water less efficiently and are less able to respond to increasing soil water deficits by osmotic adjustment than plants that are supplied with adequate levels of Zn. Previous studies also revealed that Zn protects plants against oxidative damage resulting from abiotic and biotic stresses (Cakmak, 2000), and, by this way, supports the plants cope with harsh conditions (Alloway, 2008). In spite of this common knowledge, surprisingly, insufficient experimental literature has been available about the use of Zn supplementation in table grapes to mitigate adverse effect of drought in especially the Mediterranean Zone where water stress is frequent and pervasive in viticulture areas. The current experiment was therefore undertaken, (1) to examine the effects of water stress and Zn nutrition on grapevines, and (2) to reveal whether Zn foliar application alleviates the adverse effect of water deficit under full and deficit irrigation regimes, and (3) to compare the responses of two grapevine cultivars to contrasting irrigation levels and Zn pulverization.

2. Materials and methods

2.1. Growth conditions

The experiment was conducted at the research and implementation glasshouse (38°01.814 N, 032°30.546E, 1158 m above sea level) of Selcuk University, Turkey, in 2017. Table grape cultivars 'Italia' and 'Alphonse Lavallée' were selected for the study due to their extensive cultivation in Europe and Turkey. Six years old vines, grafted on drought tolerant rootstock Richter 99 (*V. berlandieri* x *V. rupestris*) (Carbonneau, 1985), were individually cultivated in 70 L (solid volume) pots (35 cm diameter, 35 cm height) containing the substrate prepared with sterile peat (1.034% N, 0.94% P_2O_5, 0.64% K_2O, Klassman®) and perlite (0–3 mm in diameter) mixture in equal volume. The vines were drip irrigated using one irrigation line for per row equipped with single emitter of 4 L h^{-1} each per vine. The pots were isolated from the ground with plastic sheets. In the winter season, the vines were spur pruned leaving four spurs having two buds each, considering the genetically sufficient fruitfulness of basal nodes of the cultivars. After bud break (in March), six or seven shoots per vine were allowed to grow to ensure homogenous plant growth for a logical comparison of treatment effects. At the beginning of the study, nine vines per treatment were selected on the basis of homogeneity in growth. A tap water with a pH ≈ 7.5 was used for irrigation because water sources in Central Anatolia (Turkey) are alkaline. The initial pH of growth medium, pH: 6.50, was thus gradually raised to exceed 7.0 by watering the experimental grapevines with alkaline water as commonly practiced by grape growers. Over a five month period, rootzone pH values for media subjected to DI and FI were 7.18 ± 0.03 and 7.23 ± 0.02, respectively where microelement imbalance begins in many perennials. Salinity levels (1.103 and 1.407 dS/m for DI and FI, respectively) were not at critical level according to the suggestions of Walker (2010).

2.2. Experimental layout

The study layout was a randomized complete block design with two irrigation regimes [full irrigation (FI) and deficit irrigation (DI)] and two treatments (Zn pulverization and non-treated control) for each cultivar. Irrigations were scheduled according to soil water matrix potential (Ψm) levels using several tensiometers (The Irrometer Company, Riverside, CA). In order to optimize the accurate tensiometer values for continuously monitoring of substrate matrix potential at two different levels, initially, the peat-perlite substrate (pot) water storage at field capacity was calculated following the methodology described by Satisha et al. (2006). For this, briefly, two randomly taken pots filled with known volume of oven-dried growth media for each group of FI and DI were irrigated with known quantity (5 L) of water up to saturation of substrate. Then the pots were placed in the buckets and maintained for 6 h to attain the field capacity after draining of the gravity water from larger pores. After six hours, the amount of the drained water in the bucket was counted as 4.23 L and was subtracted from total amount of water applied initially. The calculated value (770 mL) was considered as FI. Forty percent of FI (308 mL) was considered as DI (Sabir, 2016a; b). These water amounts were used for start levels. Two tensiometers for each treatment were employed for a long-term control and expression of substrate water depletion (Young and Sisson, 2002), in terms of Ψm following the slightly modified procedure described by Myburgh and van der Walt (2005). Tensiometers were placed at a depth of 20 cm and approximately 12 cm away from the trunk. Changes in Ψm were continuously recorded with five consecutive daily readings at around 13:00 pm as well as before and after irrigations (Okamoto et al., 2004). Repeated readings showed that the midday matrix potential values were persistently around 10 ± 3 cb and 38 ± 4 cb for FI and DI conditions, respectively. The start value of watering for FI group vines was adjusted to 12 cb, which is about the lower limit of the easily available water in substrate. In order to practice DI, drip irrigation system was started when Ψm reached 40 cb (the level at which slight wilting occurred) and was terminated at matrix potential of 34 cb. Tensiometer readings during the study were presented in Fig. 1. Relatively higher air temperature in the glasshouse was kept to simulate the typical semi-arid Mediterranean climate. During vegetation period, daily air temperature and relative humidity, recorded using data logger (Ebro EBI 20 TH1) inside the glasshouse, were 26.4–40.8 °C and 23.2–43.7%, respectively (Fig. 2). In the hot and dry days, excessive heat accumulation in glasshouse was avoided by opening the roof and sidewall windows as well as slight whitewash

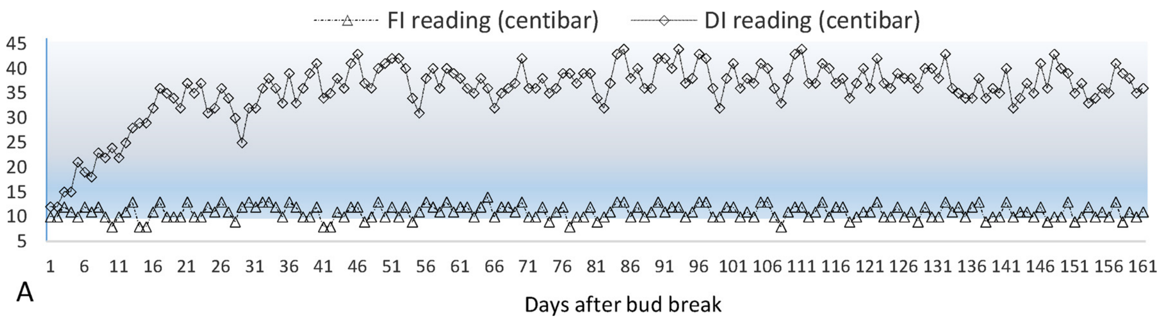

Fig. 1. Irrometer readings (centibar) recorded at midday between bud break and shoot growth cessation.

painting (providing approx. 15–20% light reflection) to keep shoot tips and young leaves from burning. Under this condition, the instantaneous daylight intensity inside the glasshouse was between 60,700 and 83500 lx (Lutron LX-105) at around 13:00 pm.

For Zn treatment, each irrigation block was further divided into two homogenous parcel. The vines belonging to Zn treatment groups were pulverized with an environmentally friendly fertilizer (E-Zn with warranted content 15% zinc in 100% EDTA form stable at pH: 2–10) two times per vegetation, namely just before flowering and at berry set stages. Leaves and the developing green clusters were pulverized using 1% concentration at application rates of 125 mg per vine, according to the directions of manufacturer.

2.3. Measurements and analyses

Physiological responses of mature leaves to irrigation and Zn treatment were investigated at véraison with the measurements stomatal conductance (gs) and chlorophyll concentration estimation at around berry set stage. The gs of leaves were obtained using the 5th or 6th leaf of the shoot tip from each shoot of vines from 09:30 to 11:30 h (Sabir and Yazar, 2015). Fully expanded but not senescent sun-exposed leaves at the outer canopy were used for measurements (Johnson et al., 2009). The gs was measured near the central vein of the leaf blade (Düring and Loveys, 1996) with a steady state porometer (SC-1 Leaf Porometer) (Zufferey et al., 2011) and was expressed as mmol H_2O m^{-2} s^{-1}. The same area for all leaves was chosen to put porometer censor (Miranda et al., 2013), since instantaneous gs may be altered over such a large leaf. Chlorophyll contents of leaves (the 5th or 6th leaf at the shoot tips) were estimated by using portable chlorophyll meter (Minolta SPAD-502, Japan).

Growth responses of the vines to treatments were determined with investigations on leaf and shoot development. At véraison, leaf fresh mass was obtained from fully expanded healthy mature leaves of representative grapevines of each treatment (Tramontini et al., 2013). Fifteen leaves per treatment were immediately weighed with an analytical scale, with precision of 0.0001 g. For macro- and microelement analyses, the healthy mature leaves on the cluster nodes (15 leaves per treatment) were collected, dried and ground at véraison stage (Bonomelli and Ruiz, 2010). Quantitative multi-element analysis was performed by inductively coupled plasma optical emission spectrometry (Vista-Pro Axial,Varian Pty Ltd, Mulgrave, Australia). Element analysis results were checked using certified standard reference materials obtained from the National Institute of Standards and Technology (Gaithersburg, MD, USA). Shoot length (all the scion shoots were measured with a sensitivity of 1 mm) was measured at the end of growth period around the cessation of shoot elongation (Sabir, 2013). The number and mass of clusters per vine was registered in all individuals at harvest time (Bascunán-Godoy et al., 2017). Fifteen representative clusters from each treatment were selected according to the norms of the Office International de la Vigne et du Vin (O.I.V., 1983) when the vines attain at least 16.5 ± 0.6°Brix juice total soluble solid to find cluster mass (g) and grape yield (g $plant^{-1}$). Sixty berries per treatment were randomly collected from the middle of fifteen clusters. The length, diameter and mass of the berry were recorded using digital compass.

2.4. Statistical analysis

The collected data were subjected to statistical analysis using a randomized complete block design. Each treatment was designed with three replicates consisting of three plants. The mean values of cultivars were compared separately, as the genotypes differ in their morphological and growth characteristics. Irrigation treatments were also considered separately to disseminate the alleviating effects of Zn on plant stress. Statistical tests were performed at $P < 0.05$ using SPSS 13.0 for Windows (SPSS Inc., Chicago, IL, USA), using the least significant difference (LSD) test.

3. Results and discussion

3.1. Growth response

As illustrated in Fig. 3, Zn treatment significantly improved the shoot growth for most cases with the exception of FI treatment in

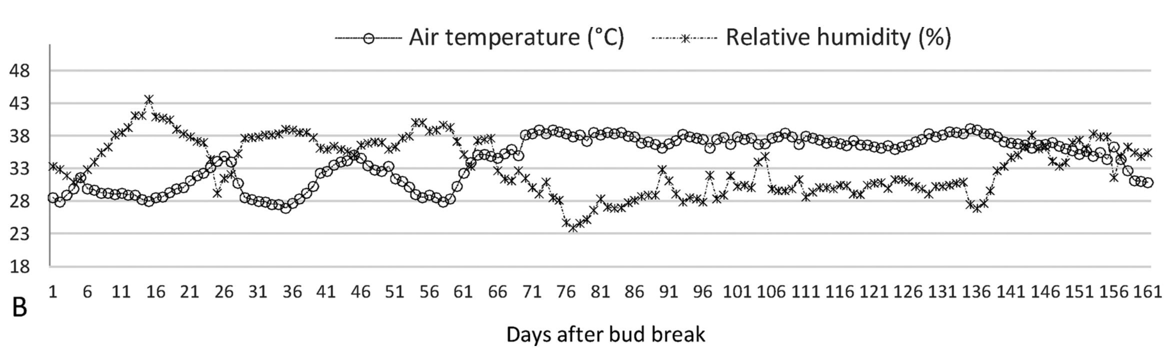

Fig. 2. Air temperature (°C) and air relative humidity (%) recorded at midday inside the experimental glasshouse between bud break (March) and shoot growth cessation (September).

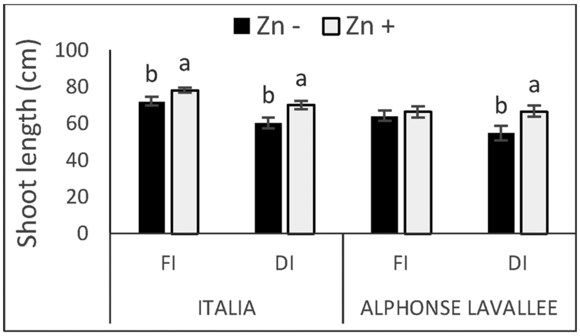

Fig. 3. Shoot length (cm) as affected by Zn treatment under different irrigation levels (FI: full irrigation, DI: deficit irrigation, Zn+: zinc treatment, Zn-: non-treatment). Values of bars indicated by different letters identify significantly different means ($P < 0.05$, LSD).

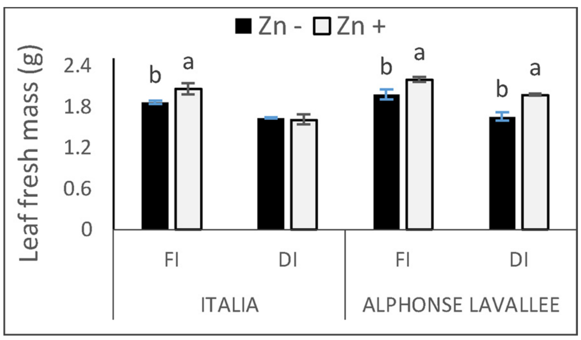

Fig. 4. Leaf fresh mass (g) as affected by Zn treatment under different irrigation levels (FI: full irrigation, DI: deficit irrigation, Zn+: zinc treatment, Zn-: non-treatment). Values of bars indicated by different letters identify significantly different means ($P < 0.05$, LSD).

'Alphonse Lavallée', while DI resulted in restriction in shoot elongation with different magnitude between the cultivars. In 'Italia' cultivar, shoot length increased from 71.9 to 77.9 cm (7.7% improvement) and from 60.1 to 69.9 cm (14.0% improvement), under FI and DI conditions respectively. Zn treatment also noticeably improved the shoot length of DI-imposed Alphonse Lavallée with a 17.7% increase from 54.6 to 66.4 cm. In particular, Zn treatment had markedly higher positive influence on shoot development under DI condition rather than FI. Mature leaf fresh mass of the cultivars were significantly increased by Zn treatments, except for 'Italia' subjected to DI (Fig. 4). Among the vines that received FI, the leaf fresh mass value of Zn treated vines was 9.6% higher than those of non-treated ones, increasing from 1.85 to 2.05 g. Such Zn-depended increase was also observed for Alphonse Lavallée under FI condition. Furthermore, there was a markedly higher (16.1%) improvement in leaf fresh mass of 'Italia' subjected to DI. Several studies have shown that drastically changes in water availability at critical phenological stages, as frequently occuring around the grape growing regions lengthwise the Mediterranean Sea, have a direct adverse effect on vegetative growth (Dry and Loveys, 1999) and canopy microclimate (Yazar et al., 2010). However, unlimited water supply results in excessive vigor, which, as well-known, has adverse effect on reproductive development (Sabir, 2016a; b) such as bud differentiation, cluster emergence, berry set, yield and quality. DI strategy may be therefore a good strategy for both efficient use of limited water sources in dry lands and for optimizing source to sink balance in even humid regions.

3.2. Physiological response

As depicted in Fig. 5, effect of Zn treatment on chlorophyll concentration was just similar to the findings on leaf fresh mass. Leaf chlorophyll concentration, determined by SPAD meter readings, was

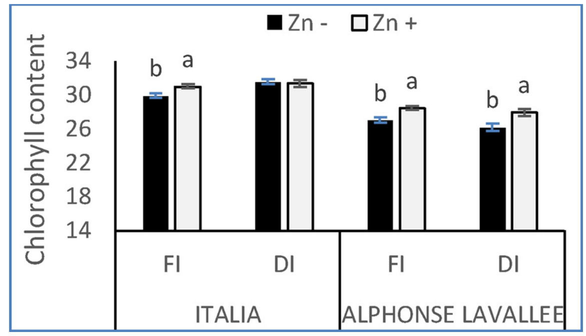

Fig. 5. Leaf chlorophyll content (mg kg^{-1}) as affected by Zn treatment under different irrigation levels (FI: full irrigation, DI: deficit irrigation, Zn+: zinc treatment, Zn-: non-treatment). Values of bars indicated by different letters identify significantly different means ($P < 0.05$, LSD).

significantly enhanced by Zn treatment, except for DI vines of 'Italia'. The effect of Zn pulverization on chlorophyll concentration of the vines was more apparent in 'Alphonse Lavallée' than 'Italia', indicating the differential effect of scion genotype on plant physiology. In a more recent study, Vajari et al. (2018) demonstrated that foliar application of Zn sulfate (2 g L^{-1}) significantly increased chlorophyll concentration and soluble carbohydrate in kiwifruit leaves. Enhancement in leaf chlorophyll concentrations in response to Zn treatment is due to the fact that Zn plays essential role in the carbonic enzyme required for chlorophyll biosynthesis (Ali et al., 2008; Graham et al., 2000).

Zn can also regulate instantaneous transpiration efficiency of leaves (Sharma et al., 1994) as essential micronutrients and an integral component or activator of many plant enzymatic groups. Stomatal conductance, a physiological process related to transpiration efficiency, significantly increased in FI vines of 'Italia' in response to Zn treatment, although none of others were not significantly affected by Zn (Fig. 6).

3.3. Changes in nutrient acquisition

Among the cultivars, K, Ca, Zn, Mn and Cu concentrations in 'Italia' leaves were always higher than those of 'Alphonse Lavallée', indicating the great influence of the scion cultivar on nutrient acquisition (Table 1). However might it be surprising, restricting the irrigation water amount did not result in remarkable imbalances in leaf blade element concentrations. Eventually, Ca contents of the leaves of overall DI vines were higher than those of FI vines. Zn pulverization resulted in general increases in P, Ca, Mg, Zn, Fe and Mn concentration in leaf blades of both grapevine cultivars, with few exceptions. In contrast, Cu concentration in the Zn treated leaves was persistently lower than those of untreated ones. K concentration of the leaf was generally similar among the irrigation levels, except for DI vines of 'Italia' where a

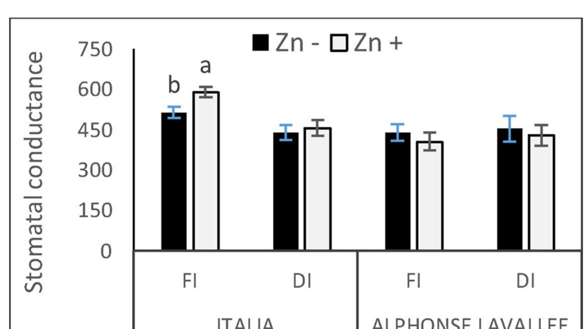

Fig. 6. Stomatal conductance (mmol H_2O m^{-2} s^{-1}) as affected by Zn treatment under different irrigation levels (FI: full irrigation, DI: deficit irrigation, Zn+: zinc treatment, Zn-: non-treatment). Values of bars indicated by different letters identify significantly different means ($P < 0.05$, LSD).

Table 1
Leaf blade nutrient concentrations as affected by Zn treatment under different irrigation levels.

Cultivar	Irrigation	Treatment	P (%)	K (%)	Ca (%)	Mg (%)	Zn mg/kg	Fe mg/kg	Mn mg/kg	Cu mg/kg	B mg/kg
Italia	FI	Zn -	0.30b	0.99	5.48b	0.61b	18.5b	106.7b	35.2b	172.0	31.9b
		Zn +	0.33a	0.98	5.70a	0.69a	30.9a	164.6a	41.8a	167.3	40.4a
	DI	Zn -	0.29b	0.96b	5.99	0.65	23.2b	130.8	47.7b	175.3a	34.0
		Zn +	0.33a	1.06a	6.24	0.69	37.6a	138.8	53.4a	155.9b	31.4
A. Lavallée	FI	Zn -	0.32b	0.51	4.36b	0.76	15.4b	113.4	30.3b	147.1	33.6
		Zn +	0.38a	0.53	5.19a	0.80	25.4a	136.9	37.8a	146.7	31.3
	DI	Zn -	0.30	0.47	4.84b	0.79	14.3b	118.9	27.8	161.9	29.7
		Zn +	0.29	0.47	5.40a	0.79	23.6a	103.8	26.2	158.8	32.9

FI: full irrigation, DI: deficit irrigation, Zn+: zinc treatment, Zn-: non-treatment. Values of bars indicated by different letters identify significantly different means ($P < 0.05$, LSD).

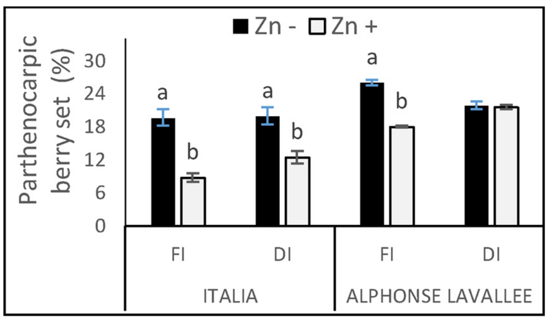

Fig. 7. Parthenocarpic berry set percentage (%) as affected by Zn treatment under different irrigation levels (FI: full irrigation, DI: deficit irrigation, Zn+: zinc treatment, Zn-: non-treatment). Values of bars indicated by different letters identify significantly different means ($P < 0.05$, LSD).

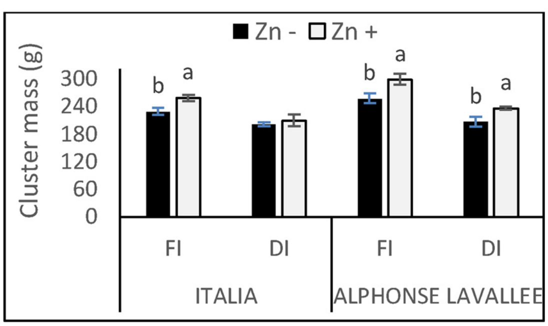

Fig. 8. Cluster mass (g) as affected by Zn treatment under different irrigation levels (FI: full irrigation, DI: deficit irrigation, Zn+: zinc treatment, Zn-: non-treatment). Values of bars indicated by different letters identify significantly different means ($P < 0.05$, LSD).

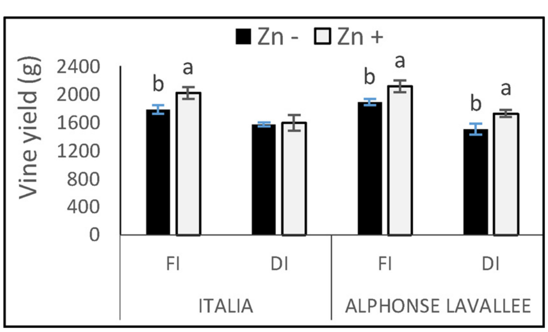

Fig. 9. Vine yield (g) as affected by Zn treatment under different irrigation levels (FI: full irrigation, DI: deficit irrigation, Zn+: zinc treatment, Zn-: non-treatment). Values of bars indicated by different letters identify significantly different means ($P < 0.05$, LSD).

significant increase occurred due to the Zn treatment. It should be underlined that the cultivars markedly differed in K uptake regardless of the irrigation. Ca acquisition of 'Italia' and 'Alphonse Lavallée' were always higher with or without Zn treatment. As expected, the most prominent increases due to the Zn pulverization were determined in Zn concentrations of leaves. In Zn content of leaf blade of FI and DI vines, there were 40.0% and 38.3% increases for 'Italia', and 39.1% and 39.5% increases for 'Alphonse Lavallée', respectively. In FI vines, Fe concentrations in the leaves of Zn treated vines were significantly higher than those of non-treated vines, whereas, Zn treatment did not significantly affect the Fe content of DI vines. Similar case also occurred in Mn concentration overall experimental vines. Changes in B concentration of the leaves in response to irrigation and Zn treatments were quite different from other elements with its complex variation. Many nutrient concentrations such as P, Mg, Cu and B determined in the leaf blades of both cultivars were similar to those found in the literature (García-Escudero et al., 2013; Sabir et al., 2014) and mostly fell within the recommended values for grapevines (Winkler et al., 1974). In all the Zn-treated vines, the measured Zn content falls within the optimal, or at least acceptable, ranges; while non-treated vines were at critical or insufficient levels. In particular, Zn contents of all the non-treated vines of 'Alphonse Lavallée' were below the optimum ranges recommended by García-Escudero et al. (2013). With a synergetic effect, Zn treatment significantly promoted the Fe absorption of both cultivars under FI condition. In fact, Fe contents of overall vines were generally lower than our previous findings on non-stressed grapevines (Sabir et al., 2012). Therefore, higher pH level of the growth media used in the present study might, most probably, be responsible for this outcome rather than water deficit because Fe deprivation is a common issue in the alkaline soils (Bavaresco and Poni, 2003; Sabir et al., 2010). Nevertheless, Zn spraying helped to improve Fe levels with a greatest impact on FI vines of 'Italia', increasing to optimum level.

3.4. Yield and quality response

As illustrated in Fig. 7, Zn pulverization significantly decreased the occurrence of pathenocarpic berry on clusters (called "hen and chicken" or "millerandage"), although there was an exception in DI subjected vines of 'Alphonse Lavallée' cultivar. In 'Italia' cultivars, Zn treatment resulted in 124% and 60% lower parthenocarpic berry set, while there was a 44.4% decrease in parthenocarpy occurrence of 'Alphonse Lavallée' clusters. Berry set is directly related with pollen germination and subsequent pollen tube growth both of which are very sensitive to water shortage. Previously, Pandey et al. (2006) reported more pollen germination and pollen tube growth with Zn application, while Marschner (2011) suggested that Zn protects pollen tube against free radicals by participating in some enzymes structure, like superoxide dismutase. In the present study, as a cofactor of enzyme responsible for certain plant growth regulators (Ali et al., 2008), Zn not only improved the general berry set, but also increased the vine yield potential by extending fruit

Table 2
Berry development as affected by Zn treatment under different irrigation levels.

Cultivar	Irrigation	Treatments	Berry mass (g)	Berry length (mm)	Berry diameter (mm)
Italia	FI	Zn -	4.23 ± 0.06b	19.7 ± 0.3b	18.3 ± 0.2b
		Zn +	4.96 ± 0.17a	20.8 ± 0.2a	18.9 ± 0.3a
	DI	Zn -	3.83 ± 0.12	19.1 ± 0.2	17.7 ± 0.1
		Zn +	3.92 ± 0.09	19.5 ± 0.6	17.8 ± 0.3
A. Lavallée	FI	Zn -	5.09 ± 0.09b	19.4 ± 0.5	18.3 ± 0.2b
		Zn +	5.39 ± 0.10a	19.6 ± 0.6	18.9 ± 0.1a
	DI	Zn -	3.94 ± 0.21b	17.6 ± 0.3b	16.5 ± 0.2b
		Zn +	4.37 ± 0.15a	18.7 ± 0.2a	17.1 ± 0.3a

FI: full irrigation, DI: deficit irrigation, Zn+: zinc treatment, Zn-: non-treatment. Values of bars indicated by different letters identify significantly different means ($P < 0.05$, LSD).

size. In particular, a remarkable increase in grape yield of 'Alphonse Lavallée' may indicate that Zn pulverization might be an advisable cultural practice for a sustainable viticulture under arid and semiarid regions. Zn is involved in diverse plant functions including photosynthesis, sucrose and starch formation, protein metabolism, membrane integrity, auxin metabolism, flowering and seed production (Alloway, 2004). Considering such physiological facts, the metabolic activities in the productive organs might be adversely affected by Zn shortage at the beginning of berry development, resulting in "millerandage" problem, a poor berry set process, encountered in both cultivars. Several studies reported significant increases in fruit set after Zn application in sweet cherry (Usenik and Stampar, 2001) and walnut (Keshavarz et al., 2011). Due to better berry set and berry development response to Zn treatment in general, cluster mass were significantly improved by Zn treatment, except for DI vines of 'Italia' where slight insignificant increase was detected (Fig. 8). In 'Italia' vines, Zn pulverization led to 11.6% increase in cluster mass under FI condition. As for 'Alphonse Lavallée' cultivar, cluster mass after Zn treatment were 14.0 and 12.45 higher than those of nontreated vines under FI and DI conditions, respectively. Vine yields were significantly higher in Zn treatments than control, except for DI vines of 'Italia' (Fig. 9). In 'Italia' vines subjected to FI, vine yield of Zn treatment was 11.7% higher than control, while yield increase percentages due to Zn pulverizations were 10.8 and 12.8% for FI and DI conditions, respectively in 'Alphonse Lavallée' cultivar. Yield increases with Zn application were mainly due to better berry development under FI and DI conditions as can be seen in Table 2. Values related to mass, length and diameter of berries were always higher in response to Zn treatment when compared to control vines. Except for 'Italia' vines subjected to DI, berry mass and berry diameter values were significantly higher in Zn treatment than control. Significant improvements in berry length were also determined in FI vines of 'Italia' and DI vines of 'Alphonse Lavallée' cultivar. Previous studies were mostly concerned about the effect of Zn fertilizer on the growth and yield of grapevines, although Zn plays a vital role in plant growth, including primary and secondary metabolisms related to yield and quality parameters (Alloway, 2004). Thus, the main results of the current research were as follows: Firstly, the promotion effects of foliage sprayed Zn on general grape berry development such as length, diameter and mass were obvious in most cases. Secondly, Zn treatment more specifically enhanced the berry size, one of the most important quality feature desired in table grapes, under DI condition in 'Alphonse Lavallée' cultivar.

4. Conclusion

Overall measurements showed that limitation in irrigation water resulted in mild stress in grapevines of 'Italia' and 'Alphonse Lavallée' cultivars grafted on 99 R rootstock. Cultivars slightly differed in their response to water deficit. Spraying the leaves and green bunches with chelated Zn supported the grapevines promoted the vegetative and generative development, acquisition of many plant nutrients. The overall response of the vines to Zn pulverization with a particular concern to DI condition, improved shoot and leaf growth, greener leaves, enhanced berry development and vine yield might allow us to recommend Zn spraying to alleviate drought stress in viticulture. Nonetheless, further investigations under field conditions are necessary in order to yield more concrete knowledge.

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